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SPHERICAL ELECTRIC MOTOR
[MOTEUR ELECTRIQUE SPHERIQUE]

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The invention concerns a spherical electric motor for direct control of a ball joint around a center of rotation. /1*

In servo-mechanism controls at times it is necessary to control an element according to two degrees of angular freedom around a spherical ball or joint with, in addition, possibly, rotation control.

The object of the invention is to propose a spherical motor with two degrees of freedom with respect to a reference axis, that is, a motor for controlling a piece that is conventionally called a rotor, to be oriented in space, with respect to an axis, around a center of rotation located on this axis. Another object of the invention is to propose such a motor, also capable of making the rotor turn around the reference axis.

The first object of the invention is achieved by the fact that the motor includes a spherical piece having a polar axis, surrounded by an enveloping piece having a spherical interior surface, leaving free two spaces in the form of annular caps diametrically opposite along an axis, called a polar axis, passing by the center of rotation, the spherical piece and the enveloping piece, the former constituting at least one inductor creating a magnetic field having components distributed approximately in the radial planes with respect to its polar axis, and the latter constituting an armature of a motor pivoting around at least one axis perpendicular to the polar axis, the former, spherical, piece thus constituting the stator and the latter,

*Numbers in the margin indicate pagination in the foreign text.

enveloping, piece thus the rotor of the motor.

In practice, the stator will be the inductor, and the rotor the armature. The two spherical forms being concentric, the interval separating them measured in the radial direction constitutes the air-gap.

In accordance with the invention, in order to make the polar axis of the rotor pivot around a first axis perpendicular to the polar axis of the stator, the piece constituting inductor(s) includes an inductor having two armatures symmetrical with respect to said first axis and each extending on a spherical axis, and, in order to make the polar axis of the rotor pivot in accordance with a steric angle, the piece constituting inductor(s) includes two inductors, each having two /2 armatures, symmetrical, respectively, around two square axes in a plane of symmetry perpendicular to the polar axis of the stator.

When, in accordance with the general case, the rotor or armature will be the spherical piece and the stator or inductor will be the surrounding unit, each armature will be of a single or assembled piece constituting magnetic cores and cylinder head of a demi-inductor or stator. Then, in accordance with the invention, each of the magnetic cores will extend in an arc centered on the center of rotation and perpendicular to the median meridian of each armature.

In accordance with a preferred embodiment, the magnetic cores and the coils of the winding, placed around the magnetic cores, are constituted, respectively, two by two, in pairs distributed on the two armatures of the same inductor symmetrically with respect to the

center of rotation and with respect to an axis of symmetry of said inductor, and two non-paired armatures are separated by an interval in which the heads of the coils of the corrugated winding are located undulating without mutual overlapping.

It is advantageous that each armature be laminated metal sheets located along the meridians.

The motor in accordance with the invention will be able, _____ in accordance with any known mode of power supply, commutable or not, to function as an asynchronous motor or a variable reluctance motor, or again in accordance with the two modes combined.

It is advantageous that the armature be made of soft solid iron, for example covered with copper in order to operate asynchronously, and including circular slots along planes perpendicular to its polar axis for a variable reluctance operation.

In accordance with an appropriate variable reluctance version, the armature includes, on each sector vis-a-vis each armature or the inductor or inductors, slots distributed along diametric planes perpendicular to the median meridian of the sector considered. It is then in accordance with the invention that the slots contain a copper conductor.

/3

The second object in accordance with the invention is achieved by the fact that, in order to make the rotor also turn around its polar axis, the piece constituting inductor(s) includes a supplementary inductor placed concentrically and creating a field turning around the polar axis of the piece constituting the inductor. For this purpose,

in accordance with the invention, each of the armatures has two series of slots and two series of crossed windings, one series of slots and one series of windings arranged along the meridians.

It is also possible to realize a set of three, and even four degrees of freedom by combining the motor in accordance with the invention, with a linear and/or rotary motor located in the rotor, and the direction of translation of which and/or the axis of rotation of which are oriented at rest along the polar axis of the motor in accordance with the invention.

Other characteristics and advantages of the invention follow from the description of the invention, which will be given below only as an example. For this reason reference will be made to the annexed figures in which:

- Fig. 1 is a schematic perspective view of an embodiment of a motor in accordance with the invention, and showing, in particular, the structure of the stator;

- Fig. 2 is a view of an equatorial cross-section of the motor shown in Fig. 1, in a smaller scale;

- Fig. 3 is an external view with a partial cross-section of a rotor in accordance with the invention;

- Fig. 4 is a version of the rotor shown in Fig. 3;

- Fig. 5 is an exterior view of another rotor in accordance with the invention represented with regard to a fraction of the notched part of the stator;

Fig. 6 is a transparent view of a stator piece for a motor in accordance with the invention having three degrees of freedom.

The description made with regard to Fig. 1 will be made with reference to a center O and three orthogonal axes passing through this center, respectively $x'ox$, $y'oy$, $z'oz$, the axis $z'oz$ being orthogonal at O to the plane xoy .

The motor includes an armature or rotor 1 of spherical shape, /4
axis of which will be privileged as a polar axis, for example bearing an active element for a transmission of force by angular displacement with respect to at least one of the two planes xOz and yOz .

The stator, designated as a whole as 2, includes two inductors 3 and 4, each of two separate pieces 5, identical to spherical internal surfaces, concentric to the exterior surface of the rotor 1. The four pieces 5 are rigidly connected to one another, the interval between their internal surfaces constituting the air gap of the motor. The four pieces 5 are distributed, not joined, in sectorial fashion on a meridian of a sphere of reference having the axis $z'oz$, centered two by two symmetrically respectively to $x'ox$ and $y'oy$. They are truncated at their ends closest to the poles of the sphere on which they are distributed, so as to leave two free spaces 6 in the form of spherical polar cups having an angle at their summit equal to 2α .

The internal face of the stator acts as a spherical bearing for the rotor which it guides without play. However, it will be possible to realize any other mode of bearing known, such as a fluid bearing made between stator and rotor or annular ball races.

Each of the pieces 5 constitutes an armature constituting, at the same time, magnetic cores 10 and yoke 11 of the demi-inductor 3 or 4 to which it belongs. For this purpose they are made of a magnetic material machined in the form of tetragons having a spherical surface delimited by two parallels and two meridians of the sphere of reference. Their interior surfaces comprise alternations of cores 10 and parallel slots 7 oriented to one another along parallels of the sphere of reference and, a single slot 7 of which has been completely represented in Fig. 1 for the sake of clarity. It is necessary to understand that the pieces 5 of the same inductor, 3 or 4, are identical and symmetrical so that the two of them constitute a stator, the windings of which appropriately supplied with current cause a rotation of the stator around the axis y' or or $x'ox$ perpendicular to /5 that, $x'ox$ or $y'oy$ on which they each are aligned centered on the point of intersection of this latter axis with the meridian of the sphere of reference.

A meridian interval 9 between two unpaired pieces 5 is provided for the location of the heads of coils 8 of an undulating winding. For the sake of clarity of the figure, only two heads of coils 8 have been represented.

If, as is preferable for the simplification of the construction, the four pieces 5 are identical, therefore each of them extends on at least 90° of the meridian of the sphere of reference.

It is seen that, by the means that have been described up to now, the polar axis of the rotor may be controlled in any angular position

in space with respect to the axis $z'oz$ of the reference sphere, that is, of the stator. If this polar axis bears a force transmission element, for example a control rod, the possibility of angular fluctuation in all directions will be limited to the angular zone limited by the free spaces 6, that is to a conical angle α around $z'oz$. If the axial zone of the rotor is hollowed out as a cylinder 24 as in Figs. 3 and 4, it can receive the stator of a linear and/or rotary motor having a externally cylindrical stator and the direction of translation and/or rotation of which will make it possible to obtain a total of three or four degrees of freedom for its rotor.

The following comments will be made with respect to the mode of winding. Two independent windings are distributed on the four pieces 5. However, two diametrically opposed pieces, although having separate coils, always are supplied with power simultaneously, constitute one winding. The number, just as the spacing, of the slots 7 is chosen as a function of the desired number of poles and speed of pivoting of the desired magnetic field.

The coils, the distribution of which will be of a known type, are located in the slots, in order that their three-phase power supply of frequency f creates pairs of poles on the stator coils p and that the distribution of the field moves at the angular velocity $\omega = \theta - f$ /6 that will be at the origin of the asynchronous system by generating currents induced in the rotor.

Each of the four pieces 5 may be laminated or not. There will be an advantage to laminate it when it will be used in an asynchronous

system in order not to generate parasite Foucault currents to the stator. There will not be one when it will be used in a variable reluctance motor. In the case where it is laminated, the direction of lamination will be perpendicular to the slots leaving room to the coils.

In one of the other of the systems (asynchronous or reluctance or the two together), the power supply of the coils of the two pieces 5, symmetrical with respect to O, of the inductor 4 will generate couples tending to make the rotor pivot around the axis $x'ox$ and the power supply of the pieces 5 of the inductor 3 to make the rotor pivot around the axis $y'oy$. In the asynchronous system the two motions may be made simultaneously and along any angular displacements. In the reluctance system, a movement of pivoting around an axis will be made only after the rotor is returned to a position for which stator and rotor are axes in the motion around the other axis.

The external form of the rotor 1 is that of a sphere, that may /7 truncated in the non-functional parts.

Depending on the operating system used, different sorts of rotor are suitable for the invention.

For the asynchronous system three types of rotor can be suitable, the last type having the best performance:

- solid soft iron having a hollow interior and the requisite thickness for the passage of flux without reaching saturation.

- solid soft iron covered by a layer having a uniform thickness of iron (the copper conducting the induced currents)

- solid soft iron provided with rotor slots, the cavities of

which are possibly partially occupied by copper. In an asynchronous system the form of the layers is of relatively little importance.

In an embodiment shown in Fig. 3, the rotor 1 is provided with circular slots 21. According to one version of the above, shown in Fig. 4, the circular slots 21 of the same rotor 1 are filled with copper 22. In this case, four meridian slots 23 are useful for closing the induced currents arising in the copper when all the layers 21 are filled with copper 22. The four meridian slots 23 may themselves be filled with copper. They are situated, with respect to the stator, vis-a-vis meridian intervals 9 receiving the heads of coils 8.

In one version having variable reluctance, shown in Fig. 5, the rotor, made of soft iron, has slots 14, the shape and orientation of which cannot be arbitrary. If the rotor 1 is divided along four meridians 12 in four parts along the axis so as to obtain four quarters 13 with respect to the stator parts, it is seen in Fig. 5 that on each of the quarters 13 the slots 14 are axes on planes passing through the center O, equidistant and perpendicular to the meridian m_1 forming an axis of symmetry of the stator piece n°1. The periodicity of these rotor slots 14 is a first number with respect to the periodicity of the stator slots 7 with respect to them. The shape of these slots, as well as the number will be a function of /8 the number of poles at the stator and determined in order to obtain the greatest variation possible of the reluctance (for a given field distribution) at the time of an elementary displacement $d\theta$.

In the version combining the two systems, asynchronous and

reluctance, the rotor will be such that the reluctance system having copper located in the interior of the slots with closure bars at the ends in order to connect all of the copper bars together so that the induced currents can circulate.

With respect to obtaining the third degree of freedom of pivoting around the axis $z'oz$, the invention has provided to locate a third winding 15 in spatial quadrature with the two others, therefore located in the meridian slots 16 perpendicular to the others for each of the four stator pieces 5 and to couple all these supplementary coils 16 so that the field distributions that they induce all turn in the same direction around the axis $z'oz$.

In this case, the slots of the stator pieces 5 will be a checkerboard, the vacant spaces of which will be occupied by the coils that thus should cross.

In this case, of course, the stator pieces should not be laminated so that the flux can circulate in two perpendicular directions.

CLAIMS

/9

1. A spherical motor for direct control of a ball joint around a center of rotation, wherein it has a spherical piece having a polar axis, surrounded concentrically by an enveloping piece having a spherical interior surface, leaving free two diametrically opposite spaces in the form of spherical caps diametrically opposed along an axis, called a polar axis, passing through the center of rotation, the spherical piece and the enveloping piece, the former constituting at

least one inductor creating a magnetic field having components distributed approximately in the radial planes with respect to its polar axis, and the latter constituting an armature of a motor pivoting around at least one axis perpendicular to the polar axis, the former, spherical, piece thus constituting the stator and the latter, enveloping, piece thus the rotor of the motor.

2. The spherical motor in accordance with Claim 1, wherein, in order to make the polar axis of the rotor pivot around a first axis perpendicular to the polar axis of the stator, the piece constituting the inductor(s) includes an inductor having two armatures symmetric with respect to said first axis and each extending on a spherical sector.

3. The spherical motor in accordance with Claim 1, wherein, in order to make the polar axis of the rotor pivot along a steric angle, the piece constituting the inductor(s) includes two inductors, each having two sectorial armatures symmetric, respectively, around two axes in quadrature in a plane of symmetry perpendicular to the polar axis of the stator.

4. The spherical motor in accordance with any one of the Claims 2 and 3, in which the armature is the spherical piece and the inductor the enveloping unit, wherein each armature is a unique piece or assembly constituting magnetic cores and yoke of a demi-inductor.

5. The motor in accordance with Claim 4, wherein each of the magnetic cores extends in an arc centered on the center of rotation and perpendicular to the median meridian of each armature.

6. The motor in accordance with Claim 5, wherein the magnetic cores and the coils of the winding, located surrounding the magnetic cores, are constituted, respectively two by two, in pairs distributed /10 the two armatures of the same inductor symmetrically with respect to the center of rotation and with respect to an axis of symmetry of said inductor.

7. The motor in accordance with any one of Claims 3 to 6, wherein two unpaired armatures are separated by an interval in which the heads of the coils of the corrugated winding are located without mutual covering.

8. The motor in accordance with any one of Claims 1 to 7, wherein each armature is laminated in metal sheets placed along meridians.

9. The motor in accordance with any one of Claims 1 to 8, wherein the armature is made of solid soft iron.

10. The motor in accordance with Claim 9, wherein the armature is made of solid soft iron covered with copper.

11. The motor in accordance with Claim 9, wherein the armature includes circular slots along planes perpendicular to its polar axis.

12. The motor in accordance with Claim 9, wherein the armature includes, on each sector vis-a-vis each armature or inductors, slots distributed along planes diametrically perpendicular to the median meridian of the sector considered.

13. The motor in accordance with any one of Claims 11 and 12, wherein the slots contain a copper conductor.

14. The motor in accordance with any one of Claims 2 to 7, 9 to 11

and 13, wherein, in order to make the rotor also turn around its polar axis, the piece constituting the inductor(s) includes a supplementary inductor located concentrically and creating a field turning around the polar axis of the piece constituting the inductor.

15. The motor in accordance with Claim 14, wherein each of the armatures include two series of slots and two series of crossed windings, one series of slots and one series of windings of which are located along the meridians.